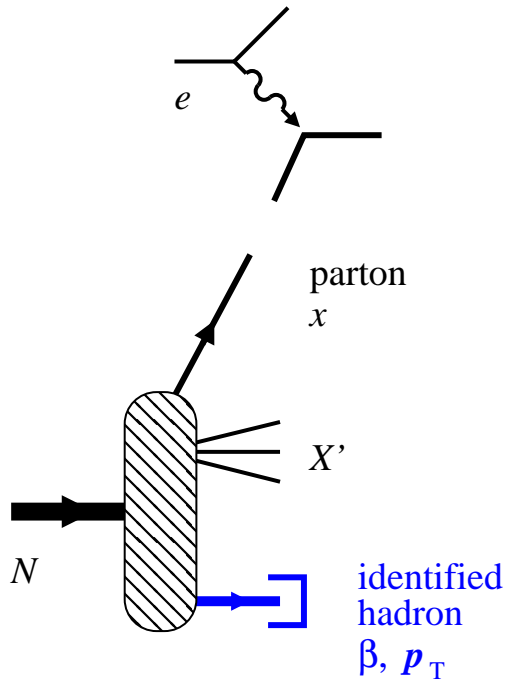


Target fragmentation in eN DIS at EIC

C. Weiss (JLab), EIC User Group Meeting, UC Berkeley, 6-9 Jan 14



Dynamics of confinement,
chiral symmetry breaking

Largely unexplored!

- Target fragmentation in DIS

Current and target regions

QCD factorization

Conditional parton densities

- Structures and dynamics

$x \ll 0.1$ Diffractive protons, neutrons
 t -channel exchange P , π HERA

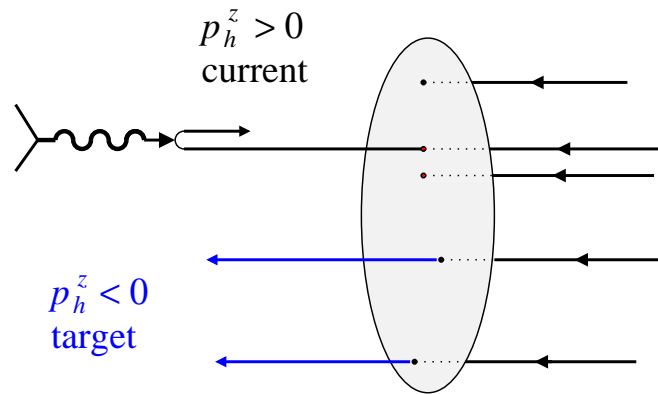
$x \gtrsim 0.1$ Hadronization of nucleon remnant,
spin/flavor effects, fragmentation
 $e + e^-$, hadron-hadron

New opportunities with EIC

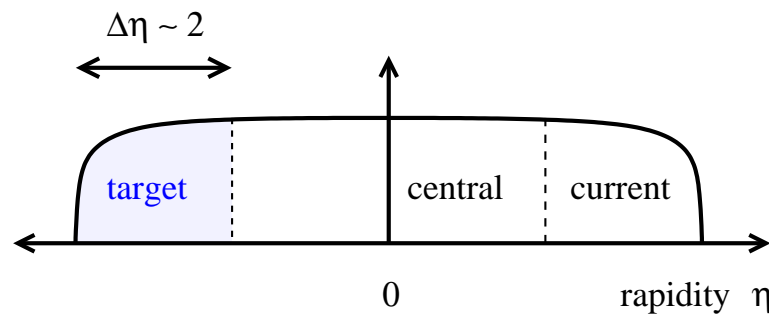
- Correlations current–target regions

Charge/flavor separation

- Detection requirements



$\gamma^* N$ center-of-mass frame



- Hadron production regions

Current fragmentation:
Decay of struck quark

Target fragmentation:
Breakup of target

Central region:
QCD radiation, slow partons

- Kinematic variables

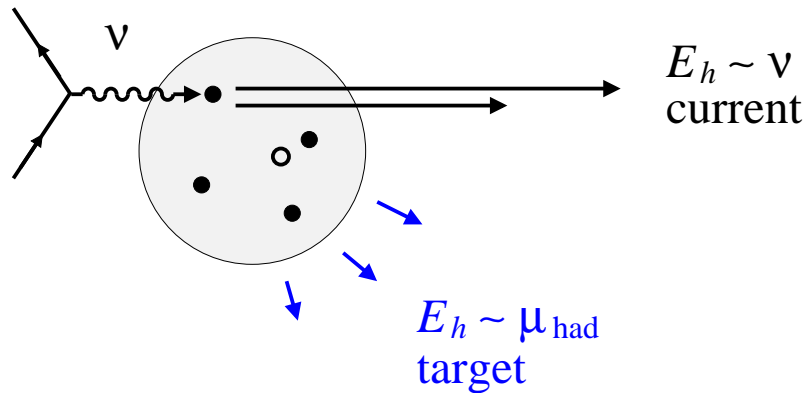
$$x_F = \frac{p_h^z}{p_{\max}}$$

Feynman variable

$$\eta = \frac{1}{2} \log \frac{E_h + p_h^z}{E_h - p_h^z}$$

rapidity

p_{hT} hadron transverse momentum



- Hadron regions in target rest frame

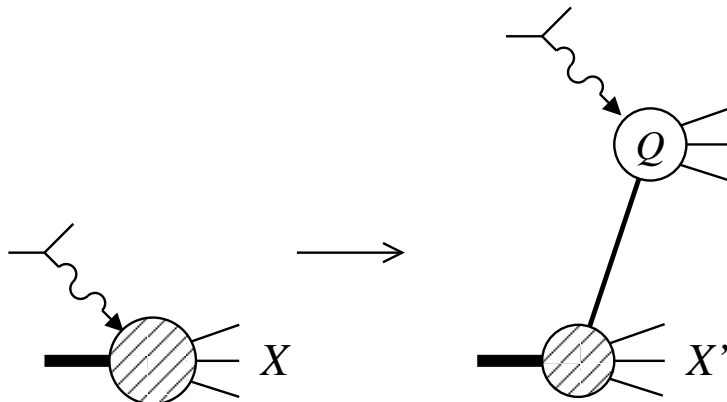
Energy transfer $\nu \gg \mu_{\text{had}} \sim 1 \text{ GeV}$

Hadrons described by energy fraction $z = E_h/\nu$

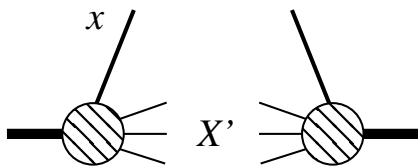
$E_h \sim \nu$ $z \sim 1$ current region

$E_h \sim \mu_{\text{had}}$ $z \ll 1$ target region

- Target fragmentation associated with slow hadrons in rest frame $|\mathbf{p}| \lesssim 1 \text{ GeV}$



$$\sigma = f(x) \times \sigma_{\text{hard}}(x, Q^2)$$



$$f(x) = \sum_{X'} \int d^2 k_T \langle P | a^\dagger | X' \rangle \langle X' | a | P \rangle_{k^+ = x P^+}$$

- Factorization

Interaction decreases at short distances:
Asymptotic freedom

Separate scales $Q^2 \gg \mu_{\text{had}}^2$

σ_{hard} calculable in pQCD

- Parton distribution PDF

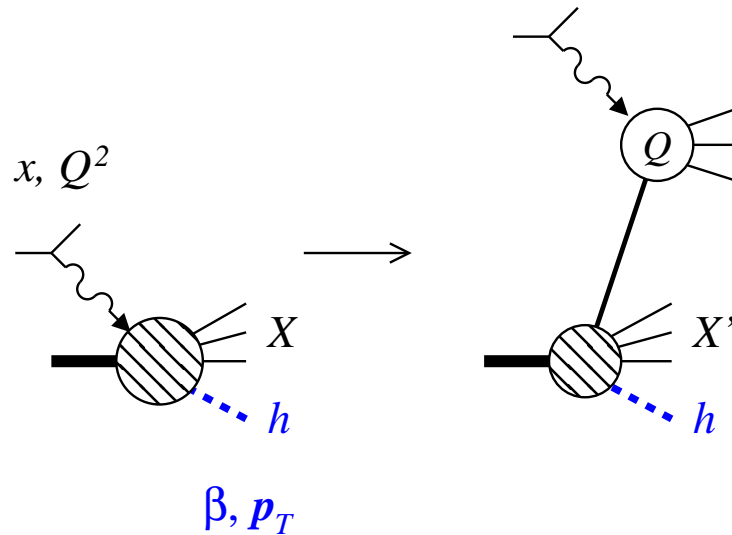
Light-cone momentum density in target,
probabilistic interpretation

QCD radiation: $\log Q^2$ dependence,
DGLAP evolution

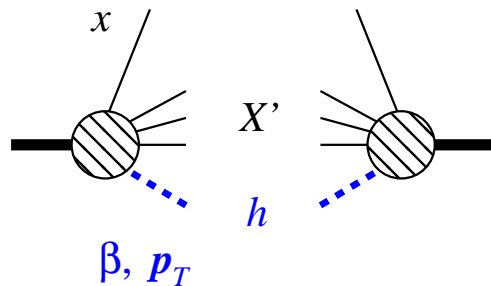
- Universality

PDF independent of hard process

Same in $\nu N \rightarrow X$,
 $NN \rightarrow X + \text{jets, dileptons}$



$$\sigma = f_h(x; \beta, p_T) \times \sigma_{\text{hard}}(x, Q^2)$$



$$f_h(x; \beta, p_T) = \sum_{X'} \int d^2 k_T \langle P | a^\dagger | h X' \rangle \langle h X' | a | P \rangle_{k^+ = x P^+}$$

- Factorization [Trentadue, Veneziano 94; Collins 98](#)

σ_{hard} same as in inclusive

Q^2 scaling for fixed $\beta, p_T \ll Q$
Can be tested experimentally

- Conditional parton distribution cPDF
[Alt. Fracture function](#)

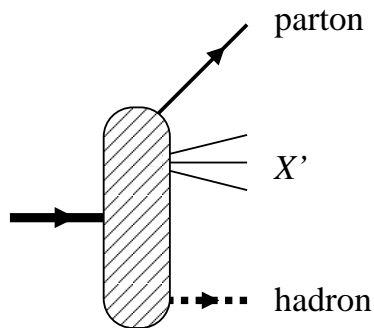
Probability to find hadron with β, p_T
after removing parton with x

$$\beta = p_h^+ / (1 - x) P^+ \text{ LC mom. fraction}$$

- Properties

cPDF independent of hard process,
expresses structure of target

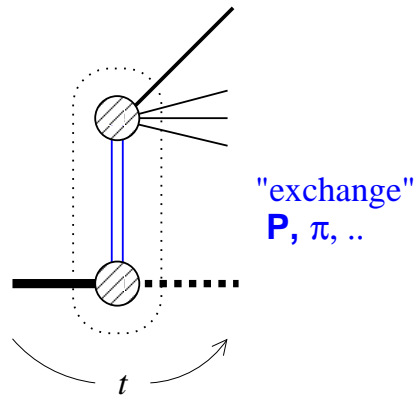
DGLAP evolution
[Collins 98: Same as PDF](#)



- cPDF is object in itself

Defined by factorization theorem, universal

Can be extracted from data



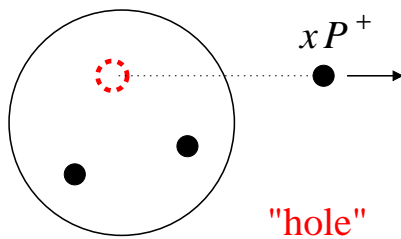
- Interpretation at $x \ll 0.1$

mainly

Partonic content of “exchange:”
Regge trajectory, single hadron . . .

Use invariant momentum transfer $t(\beta, p_T)$

Can be made rigorous in special cases: π pole

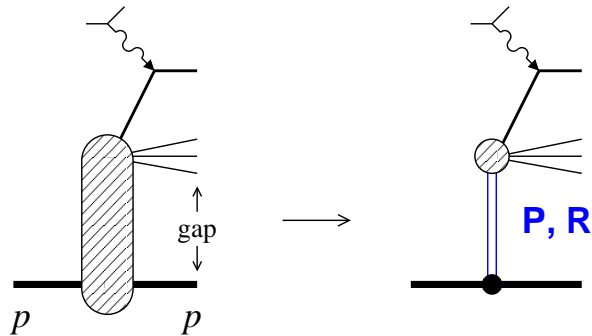


- Interpretation at $x \gtrsim 0.1$

Hadronization of nucleon with
“hole” in light-front wave function

Dynamics of chiral symmetry breaking,
color confinement

Charge/spin/flavor dependence



- Diffractive DIS $\gamma^* p \rightarrow p + \text{gap} + X$

Extensively studied at HERA $x < 10^{-2}$

Diffractive PDFs: DGLAP evolution, global fits w. DIS, jets, heavy flavors

Interpreted as partonic content of pomeron cf. soft hadronic interactions

$$f_{j/p}(x, x_P, t) = f_{j/P}(x/x_P) f_{P/p}(x_P, t)$$

pomeron flux

- Open questions

Limitations of Regge ansatz?

Slope $\alpha'_{\text{eff}}(Q^2)$, non-linear t -dependence?

Luminosity, multidimensional binning

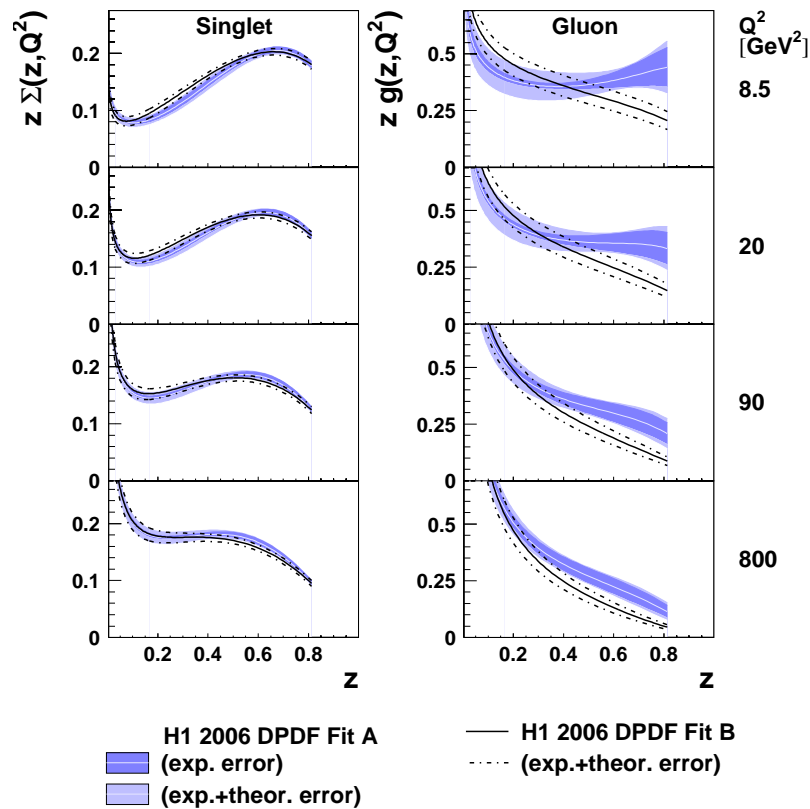
Non-singlet diffractive PDFs?

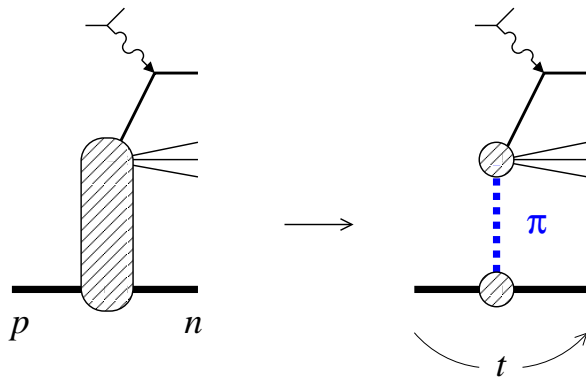
ρ trajectory, soft-hard transtion?

Correlation measurements \rightarrow later

Spin dependence of diffraction?

Polarized beams





- Charge-exchange DIS $\gamma^* p \rightarrow n + X$

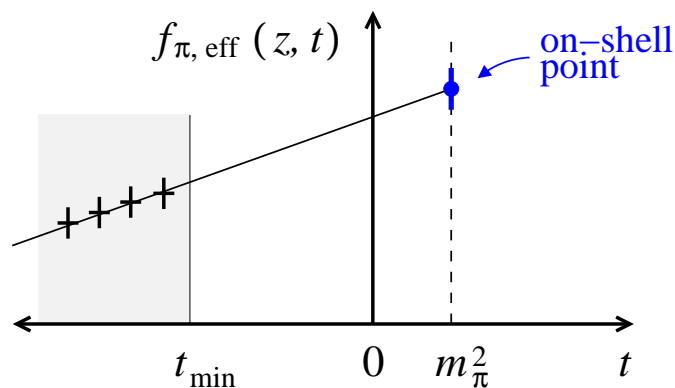
Forward neutrons at HERA $x < 10^{-2}$

JLab 12 GeV approved experiment [Keppel et al.](#)

- Pion exchange contribution → Talk Sargsian

Pole at $t = M_\pi^2$, residue given by pion PDF

Measurements done away from pole $t < t_{\min}$
Pole term extracted using on-shell extrapolation or models of non-pole background



- Pion structure with EIC

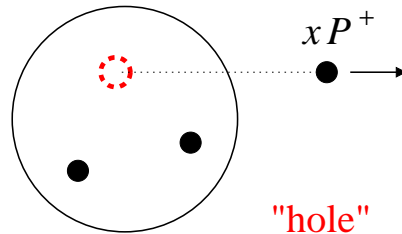
Access to $x < 0.1$ for small $|t_{\min}|$

Good resolution in neutron $\beta \approx 1 - x_\pi$
Forward detection

Access to $p_T \lesssim 100$ MeV

Optimal conditions for pion structure

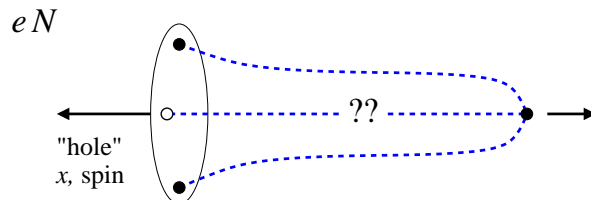
$$t_{\min} = -\frac{x_\pi^2 M_N^2}{1 - x_\pi}, \quad x_\pi > x$$



- How does nucleon with "hole" materialize?

Color neutralization dynamics?

Chiral symmetry breaking: $q\bar{q}$ pair condensate, effective spin-flavor interactions?

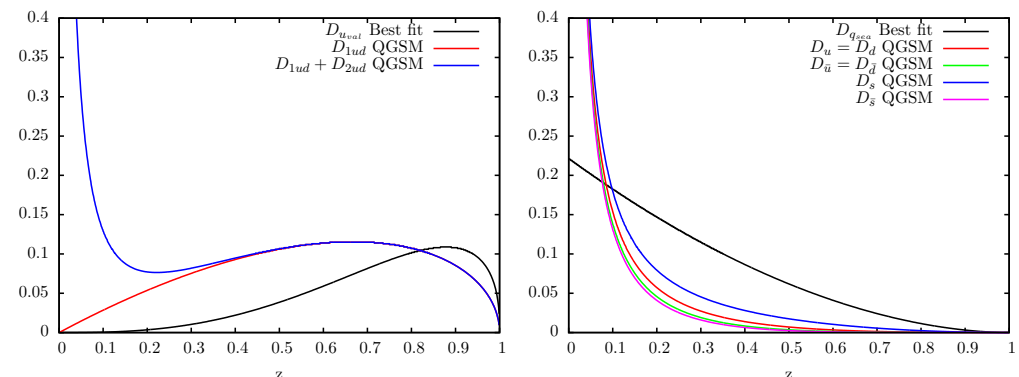


- String fragmentation model

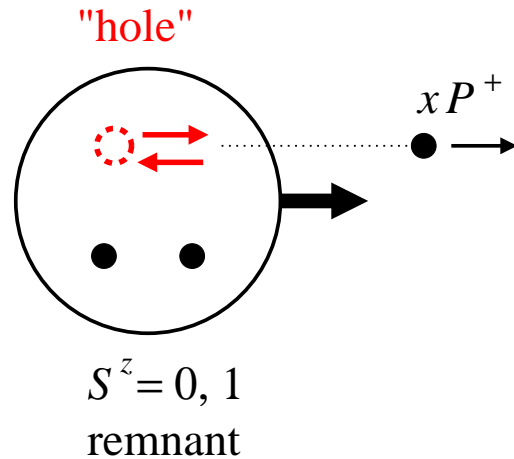
Andersson et al 80's. Basic template for color neutralization

e^+e^- $q\bar{q}$ string

e^+N $q(qq)$ string



Λ production cPDFs from neutrino and DIS data [Ceccopieri, Mancusi 12]. Strong discrepancy with string-based model [Kaidalov Piskounova]



- Polarized DIS leaves remnant system with definite spin

Study spin dependence of hadronization at fixed x and β

- Observables sensitive to remnant spin

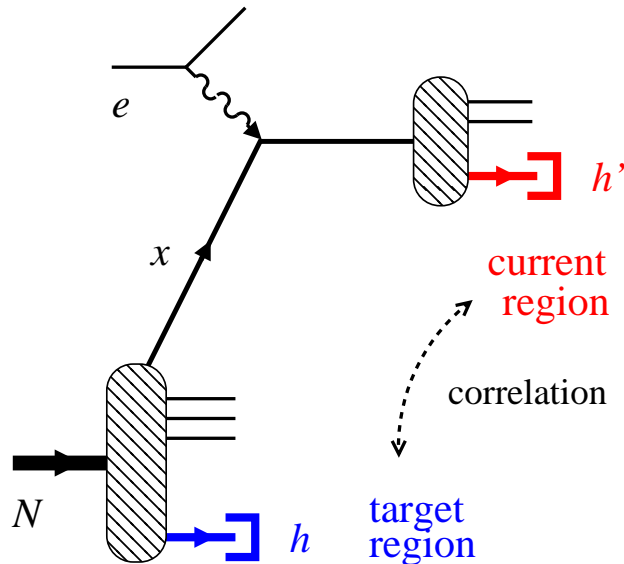
$\Delta-N$ production ratio [Strikman 13](#)

Polarized Λ production

- Azimuthal asymmetries in target fragmentation with beam/target spin
[Anselmino, Barone, Kotzinian 11](#)

$$\frac{d^5\sigma}{dx \, dQ^2 \, d\beta_h \, dp_{hT} \, d\phi_h} = [\dots] + \sum_n [\dots] \cos n\phi_h + \sum_m [\dots] \sin m\phi_h$$

T -even and T -odd structures, cf. SIDIS in current fragmentation region



- Control charge/ flavor of removed quark through current fragmentation hadrons

Singlet–nonsinglet separation with $\pi^+ \pm \pi^-$

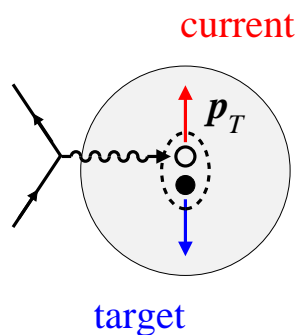
Sea quarks with current antiprotons

Strangeness with K^+, K^-

- Feasible with EIC

CM energy for current–target separation

Luminosity for correlation measurements



- Beyond collinear: p_T dependent correlations

Sea quarks in correlated pairs of size $\rho_{\text{chiral}} \ll 1 \text{ fm}$

Back-to-back correlations between current and target hadrons

Kinematics where QCD radiation suppressed. Schweitzer, Strikman, CW 12

Dynamical origin of intrinsic k_T ? \rightarrow Talk M. Baker

Good acceptance for forward protons/neutrons with longitudinal momenta $p_{\parallel}/p_{\text{beam}} \sim 0.3 - 1$

Good longitudinal momentum resolution near $p_{\parallel}/p_{\text{beam}} \sim 1$

Transverse momentum coverage and resolution at $p_T \ll 100 \text{ MeV}$

Resolution and identification forward pions/kaons with $p_{\parallel}/p_{\text{beam}} \lesssim 0.3$

Summary

- Target fragmentation as dynamical manifestation of color confinement and chiral symmetry breaking
- Conditional PDFs as unifying concept: Defined through factorization theorem, extracted from data, interpreted in dynamical models
- EIC has unique potential for target fragmentation studies
- Further: Target fragmentation in $eA \rightarrow$ Talks M. Sargsian, Ch. Hyde